Journal of Cleaner Production 89 (2015) 165–173

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Comparative Life Cycle Assessment of ceramic versus concrete roof tiles in the Brazilian context

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A R T I C L E I N F O

Article history:
Received 25 June 2014
Received in revised form
6 November 2014
Accepted 7 November 2014
Available online 15 November 2014

Keywords:
Life Cycle Assessment
Ceramic tiles
Concrete tiles
SimaPro
IMPACT 2002+
Brazil

A B S T R A C T

The Brazilian ceramic industry is responsible for providing more than 90% of the roof coverings and wall bricks in the country, producing more than 15 billion pieces per year. In order to compare the life cycle impacts of ceramic versus concrete roofing tiles and identify potential improvements in ceramic products, we carried out a life cycle impact assessment of both products. This study aimed to compare the life cycle impacts of ceramic and concrete roof coverage over 1 m^2, with an assumed life time of 20 years in Brazil. Nine different sensitivity analyses were carried out followed by a Monte Carlo uncertainty analysis to verify the robustness of the study. The results show that ceramic tiles appear to have less impact than concrete tiles on Climate Change, Resource Depletion and Water Withdrawal, while for the remaining damage categories, Human Health and Ecosystem Quality, the difference between the two alternatives was too low to be considered significant. The use of wood chips led to significant impacts, mainly related to respiratory inorganics. Assessment of the data quality identified that the data is of generally high or acceptable quality. The sensitivity analysis and uncertainty assessment show that the conclusions are robust.

1. Introduction

The construction industry is increasingly concerned with the environmental impacts over a building's life cycle and is aiming for the improvement of environmental indicators of sustainability (Gabaldón-Estevan et al., 2014; Koroneos and Dompros, 2007; Nicoletti et al., 2002; Ortiz et al., 2009; Sharrard et al., 2008; Traverso et al. 2010). The construction sector is the one that most consume raw materials by weight (Koroneos and Dompros, 2007) and ceramic and concrete elements are among the ones mostly used in buildings (Koroneos and Dompros, 2007; Wattanasiriwech et al., 2009). Therefore, the choice for greener products and ways of cleaner production is at priority (Shu et al., 2010) and environmental assessments can provide information needed for the choice of specific processes or materials. Life Cycle Assessment (LCA) is a recognized approach to assess the environmental impacts associated with a product life cycle or a service from the extraction of raw-materials through to the end-of-life treatment (Curran et al., 2011; EEA, 1997), helping with the identification of potential improvements of the product and involved unit process environmental performance. It has also been applied as a tool to guide decision-making, aiming at better environmental performance of products and the comparison of different alternatives of building elements (Asif et al., 2007; Kellenberger and Althaus, 2009; Mithraratne and Vale, 2004).

Following the publication of a few studies evaluating the environmental performance of roofs (Bribián et al., 2011; Kosareo and Ries, 2007; Saiz et al., 2006), and two Life Cycle Assessments of ceramic tiles in Spain (Ibáñez-Forés et al., 2011; Bovea et al. 2007), the Brazilian National Ceramics Industry Association (ANICER) identified the need to evaluate the potential environmental

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http://dx.doi.org/10.1016/j.jclepro.2014.11.029

impacts associated with the life cycle of ceramic roof tiles, in order to compare them with an equivalent concurrent product (concrete tiles). The Brazilian red ceramic industry consists of more than seven thousand companies from micro to medium size enterprises, being responsible for more than 90% of the roof coverings in the country (Schwob et al., 2009). In 2011 the production of roofing tiles contributed 36% of the total production in the sector, represented by 1,300,000,000 pieces/month and the use of 30 Mt of clay/year (ANICER, 2011).

The aim of this study is to compare the life cycle impacts of ceramic roof tiles with equivalent concrete tiles in the Brazilian context. Moreover, the analysis helps one to understand the effects on different impact and damage categories of the ceramic and concrete life cycle stages. The influence of the central assumptions and variables selected was assessed by carrying out a sensitivity analysis. The results of the study were reviewed by ceramic and concrete specialists from Brazil to enhance quality and credibility.

2. Materials and methods

2.1. Goal of the study

The goal of the study is to compare the life cycle environmental impacts of roof covering over a 1 m^2 area using ceramic roof tiles with the same function fulfilled with similar concrete roof tiles.

2.2. Scope of the study: functional unit and system boundaries

The functional unit was defined as the "coverage of one square meter of roof with tiles, for a duration of 20 years in Brazil", aiming to protect a building interior from weather events and to assure thermal insulation. The assumptions made in this study are based on average conditions present in the country. Due to the lower thermal performance of concrete tiles when compared to ceramic ones (Mariane, 2012), it may be necessary to apply an aluminum insulation layer to reduce heat radiation of concrete tiles. In this study, the baseline scenario assumed that building energy use is similar between the two systems without the insulation layer. However, the assumption of adding an aluminum layer for the concrete tiles system was tested in the sensitivity analysis. For the ceramic tiles, it was assumed that 16 tiles are needed to cover an area of 1 m^2 of roof, amounting to a total weight of 38.4 kg (i.e. 2.4 kg per ceramic roof tile), while for concrete roof tiles these values corresponds to 10.4 tiles and 46.8 kg (i.e. 4.5 kg per concrete roof tile), respectively (Table 1). The structure built to support the roof is considered equivalent for both alternatives.

The boundaries for both systems were defined from the extraction and processing of raw materials to the end-of-life stage, i.e. landfilling. The ceramic tile system boundaries are represented in Fig. 1, for which clay extraction was assumed to be done with the aid of retro-excavators, wheel loaders and bulldozers. Four processes were considered in the manufacturing of ceramic tiles. The preparation of the clay dough was assumed to be carried out with a loading shovel and by means of mechanical mixing. This operation is followed by the mechanical shaping of the tiles using molds. During the drying phase, the water content is reduced from 25% to 3% (SEBRAE, 2008) and tiles are finally cooked to reach its solid final outcome. The elimination of water is done via natural evaporation, through the use of an air current. During the firing stage, carried out in furnaces, with temperatures nearing 950 °C, (Monteiro and Vieira, 2004) wood chips supplied by the wooden furniture industry are used as fuel. The losses reach 1.5% and are reprocessed and reincorporated into the dough to a maximum of 5% or sold for tennis court terrain. Details of material and energy inputs of the life cycle of ceramic roofing tiles are available in Table A.1, of Appendix A.

For concrete tile manufacturing (Fig. 2), clay is assumed to be obtained in the same way as for the ceramic tiles, while sand is assumed to be either extracted from river sand pits or artificially produced by crushing rocks (artificial sand). For the latter, a sensitivity analysis was carried out in order to verify differences in the results. Limestone, the main raw-material for cement production, is extracted from quarries with the use of explosives. Seven main processes were identified in the production of concrete tiles: from crushing and grinding of limestone to coating of the tiles. Limestone (90%) is crushed before being kept in storage bays, along with clay (10%). This mix is then crushed and grinded to obtain a particle size of about 0.050 mm. The resulting flour, or raw meal, is introduced in an oven and initially heated to be then introduced in a rotary kiln, with temperatures up to 1450 °C to obtain the clinker (SNIC, 2011). Cooling then takes place, down to 80 °C, and then the clinker is mixed with gypsum and additives to obtain the commercial cement mix. The latter is mixed with sand (70%) and water (10%) to produce the concrete to shape the tiles. A coating agent is applied on the tiles as a protection layer. The material and energy inputs to the life cycle inventory of concrete roofing tiles are available in Table A.2 of the Appendix A.

For the transportation average scenarios, trucks are assumed to run a total distance of 108 km each way between the clay quarry and the ceramic tiles manufacturing plants, and 150 km from the places of extraction of sand, limestone and clay to the cement plant. Moreover, an additional distance of 300 km was considered in the transportation of cement to the concrete tile manufacturing plant. After the final products are ready, ceramic roof tiles are dispatched in bulk to storage silos and to the end customer (depots), over a distance of 5 km. Concrete tiles are transported after packaging.

For ceramic tiles, a total 120 km average distance was assumed for the transportation from manufacturing plants to storage and then to end customer, while for concrete the total distance was assumed to be 450 km. These differences in transport distances were defined based on national data, provided by ANICER, for the main producing states. The differences between ceramic and concrete industries are mainly due to the higher number of ceramic production facilities per area, as ceramic production units are mainly small and medium size enterprises, mostly family-owned business (FIESC, 2011) and long-distance transport is not economically viable (FIEMG, 2013). The data has gone through a peer review process, validated by external independent experts, from the concrete and ceramic industry. A sensitivity analysis was also carried out and the final result would have not changed up to a 500 km transport distance for ceramic tiles. For both case scenarios, the transport weight was adjusted to the heavier tiles. An end-of-life scenario was built upon the current practice of landfilling the lost pieces or disassembled ones and a transportation distance of 50 km was assumed. Losses during the laying were estimated to be 1% for both alternatives, but were not considered in this study, based on the cut-off criteria used. Table 2 displays the general system description for ceramic and concrete roof tiles, containing details for each of the life cycle stages.

Table 1
Key characteristics (weight, tiles per area, lifespan) of the studied roof tiles (ceramic and concrete), based on average data in the Brazilian context.

Characteristics	Ceramic roof tiles	Concrete roof tiles
Weight (kg)	2.4	4.5
Roof coverage (tiles/m^2)	16	10.4
Total weight per m^2 (kg)	38.4	46.8
Lifespan (years)	20	20